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Review

Trends and frontiers of MEMS

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Abstract

Since 1988, the MEMS has advanced from the early stage of technology development, device exploration, and laboratory research, to the mature stage of mass production and applications, as well as launched exploration and research in many new areas. For the trends of MEMS in the next 5–10 years, people with different background would have different views and projections. This article will present examples to illustrate the suggested future trends, as some of us see it.

From the present MEMS orientation, the future trends of MEMS can be suggested as below:

1. *Transfer the traditional useful MEMS to large scale applications, to establish mass markets*. This would build up MEMS industries to support the sustained MEMS research and development. There are two major directions: (A) Reduce cost, raise yield and efficiency to cultivate mass markets. (B) Raise system performance to meet the special needs.
2. *MEMS network*. There are needs of having many *different* functional systems and many *similar* functional systems working together to perform required big tasks.
3. *New materials*. Besides silicon and semiconductors, many other materials can be used for MEMS.
4. *Explore new frontiers*. Many new Frontiers of research and application were developing. More will be open up. Such as: (A) biological research and medical instruments; (B) micro-energy sources—micro-fuel cells, environmental energy converters, remote energy supply techniques, etc.; (C) radio frequency and optical/IFR communication; (D) environmental monitoring, and protection; (E) ocean and water-way studies; (F) nano-micro-mixed technology.

This article attempts to present the views of some MEMS educators and researchers in an over simplified form. It is hoping that this would stimulate more valuable discussions that may be valuable to planners of MEMS development and general readers.

Keywords: MEMS; Trends and frontiers

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1. Introduction

Since 1987, micro-electro-mechanical-systems (MEMS) has advanced from the early stage of technology development, device exploration, and laboratory research, to the mature stage of quantity production, practical applications, and expanding to many new areas of exploration and research. As for the trends of MEMS research and industrial development, in the next 5–10 years, people with different background would have different views and projections. This paper attempts to outline the views of some MEMS educators and researchers in an over simplified presentation. The authors hope that this material would serve as references to the researchers and the planners of MEMS development to stimulate more valuable discussions and studies.

In the first 10–15 years, besides a few success stories like ink-jet printers, automobile sensors, digital mirror displays, MEMS activity mainly devoted to the establishment of micro-fabrication technology, device design, and the verification of research ideas to lay the foundation for this field and extend to explore other areas that MEMS may has good potential. In recent years, MEMS is maturing and moving gradually to field applications, to establish MEMS industries, and to support sustainable MEMS research and industrial growth.

In the early stage of MEMS development, there are many important historical events or developmental monuments of general interests. A few selected ones are given below.

In 1954, a paper, measured the piezoresistivity coefficients in germanium and silicon, was published by Professor C. S. Smith, on sabbatical leave from Western Reserve University, Cleveland, OH, USA, to work in Bell Telephone Laboratory. These data paved the way for today's piezoresistive sensors design, including pressure, displacement, and strain sensors [1].

In 1959, the paper "There is plenty of room at the bottom", by Professor Richard Feynman, was published [2]. It ushered-in the New Era of micro-machining, micro-devices and nano-technology.

From 1960 to 1970, resonant gate transistors [3], accelerometers [4], pressure sensors and silicon based strain sensors were fabricated. Fig. 1 is a resonant gate transistor of 1967 [3].

In 1981, "Journal of Sensors and Actuators" was published and "the First International Conference on Solid-State Sensors, Actuators and Microsystems" (Transducers 81) was held in Boston, USA.

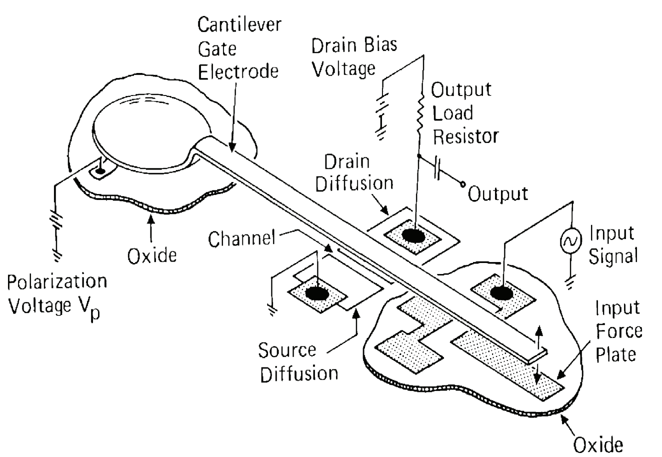
In 1982, Professor K.E. Peterson published the paper, "Silicon as a mechanical material" [5]. The micro-machining

In 1987, the First "MEMS" related Workshop on "Micro-Robots and Tele-operators", was held at Hyannis, MA, USA. This and the following workshops in USA and other parts of the world, introduced the terms micromachining, micro-systems, micro-fabrication-technology, and micro-electro-mechanical-systems (MEMS).

In 1992, the first issue of "Journal of Micro-Electro-Mechanical-Systems" (JMEMS) was published.

In the last 20 years, intensive laboratory explorations were made. A few well known industrial success cases in MEMS are:

1. MEMS based inkjet head from Hewlett-packard. These inkjet heads occupied a majority of today's inkjet printer market with more than 1 billion US dollars.
2. Pressure sensors from Nova Sensors of general motor.
3. Accelerometers and gyroscope from Analog Devices
4. Digital light processing (DLP) from Texas Instruments. Digital light processing (DLP) is a revolutionary way to project and display information based on the digital micro-mirror device (DMD). The research started in 1976 and it took about 20 years to finalize and commercialize this product. Today, the DLP system was used by more than 40 manufactory world wide.
5. Bio-chips and micro-fluidics devices
6. MEMS applications in communication – RF, Optical, IFR communication components, used in cell phones and Internet systems.



2. Trends and frontiers of MEMS

Gauged from the past MEMS development and orientation, the future trends of MEMS research and development, as the author see it, may be summarized as below.

2.1. Transfer research to applications

Transfer the established traditional MEMS devices and systems, which are proved to be useful, to large scale applications, to mass markets, thus build up MEMS industries to support sustained MEMS research and development. In 2005, the MEMS components world market is about 5 billions US dollars. As MEMS technologies and fundamental research accumulate, and the pace of industrial application and business development accelerates, the future MEMS market potential will be great. At the same time, the rapid advances in integrated circuits and the market demand on new products provided MEMS a very good opportunity to flourish. In a sense, the New Era of MEMS is arriving.

Fig. 2 is an interesting figure which was presented by Dr. K.E. Petersen in “the 13th International Conference on Solid-State Sensors, Actuators and Microsystems, 2005” (TRANSDUCERS ’05) [6]. There are two curves in the figure. The upper one is the well-known Moore’s law in IC industry, which predicts the transistor density of integrated circuits doubles every 18 months and with doubled performance. The MEMS device shown in the lower curve approximates the time advance of complexity level (electronic and mechanical elements/chip) from pressure sensor, accelerometer, ink-jet head to digital micro-mirror device

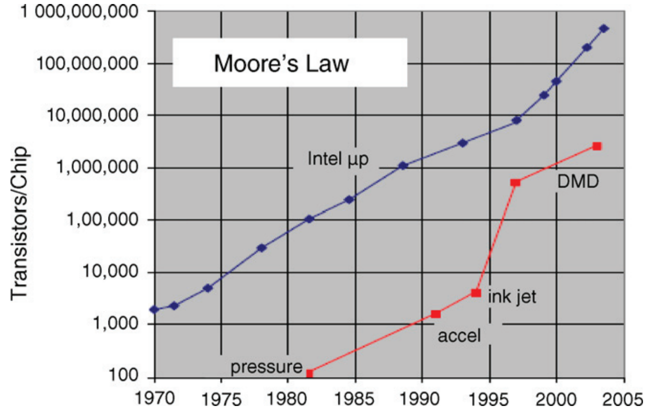


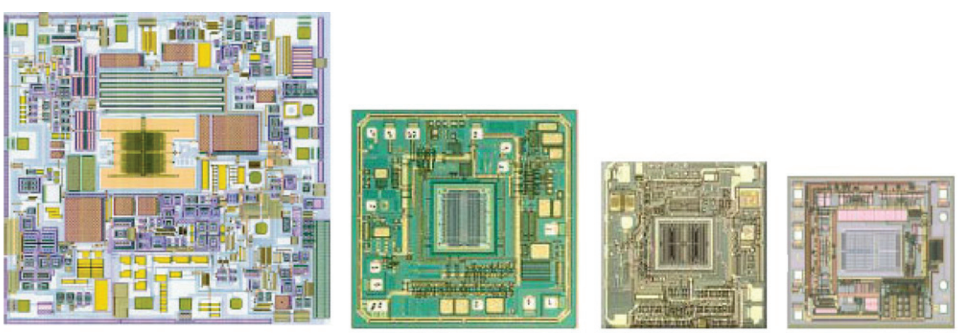
Fig. 2. Moore’s law in MEMS [6] [Courtesy of Dr. Kurt Petersen of SiTime, USA].

(DMD). Interestingly, the MEMS curve almost has the same trend as Moore’s law. We could not predict whether the development of MEMS will accurately follow this curve but what we can tell is that the MEMS field will advance with accelerated pace.

As the MEMS field evolves from research mode to application mode, there are three major directions.

2.1.1. Develop low cost, high efficiency, and mass produced devices

These devices will be parts of practical and functional systems used in aerospace, military and scientific research as well as automated manufacturing industries and consumer products. Such as sensing and controlling devices/systems used in auto-



	ADXL50 (1994)	ADXL76 (1996)	ADXL78 (2001)	ADXL180 (2006)	
Die Area	10.8	5.4	2.7	2.5	mm2
MEMS Area	0.43	0.38	0.27	0.22	mm2
% MEMS	4.0%	7.0%	10%	8.8%	
Cs	100	100	40	160	fF
fo	25.0	24.5	24.5	12.5	kHz
Noise	6.0	1.0	1.0	1.0	mgee/ rt.hz
Offset	3.0	1.0	0.5	0.5	gee

mobile, manufactory, building, and everyday life applications. For example, Fig. 3 is the evolution roadmap of accelerometers made by analog devices [3]. MEMS accelerometers have been widely used in air bag system in automobile industry, robotics, and everyday consumer products.

2.1.2. Research on high performance, functionality and reliability systems

Efforts may be directed to develop high performance, functionality, and reliability systems to achieve desired requirements for high-end, high-priced applications. For example, develop better components used in cell phones and mobile personal computers, and to explore challenging applications in aerospace, military, medical research and environmental monitoring. This trend requires MEMS research to integrate with design of ASIC, packaging, energy sources and management, and software development to achieve high performance, functional, easy-to-use and reliable micro-devices and systems.

Fig. 4 is a wireless MEMS strain sensor with rf powering and wireless data telemetry developed in Case Western Reserve University, which monitors real time strain information on rotating shafts to understanding material fatigue and increase system reliability. The system is powered by rf powering, the strain information is sent out wirelessly by data telemetry. The core is a capacitive MEMS strain sensor and an interface IC. The strain information is first sensed and transferred to capacitive variation, which is converted to voltage information by the low noise interface IC, and then wirelessly telemetered out after A/D conversion. At the same time, the interface IC converts rf coupled energy into stable dc power and control signal. Fig. 5 is an illustration of packing design for easy installation and increased reliability. By using the integrated system approach, the high performance strain sensor system can measure strain from dc to 10 kHz, with a dynamic range of ±(0.1–1000) με [8].

2.1.3. Integrate related sensors and actuators as a functional chip/system

Fig. 6 is a single-chip multi-modes chemical gas detection system developed in Swiss Federal Institute of Technology [8], which integrates multiple chemical sensors with CMOS IC on the same chip. The system can detect mass change, thermal change, capacitive change and temperature change due to chemical reactions, simultaneously. Fig. 7 is a photo of the sensor chip with a size of 7 mm × 7 mm. The system is fabricated in a silicon chip to achieve system miniaturization, increased reliability and low cost. This is a good example of system integration.

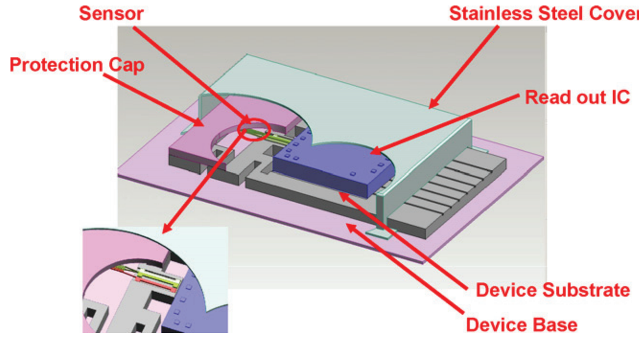


Fig. 5. Illustration of the wireless MEMS strain sensor system package.

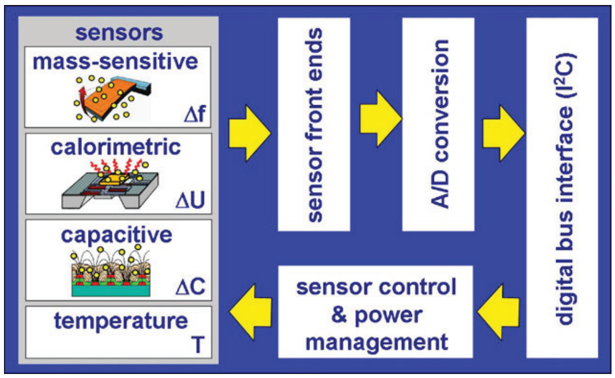
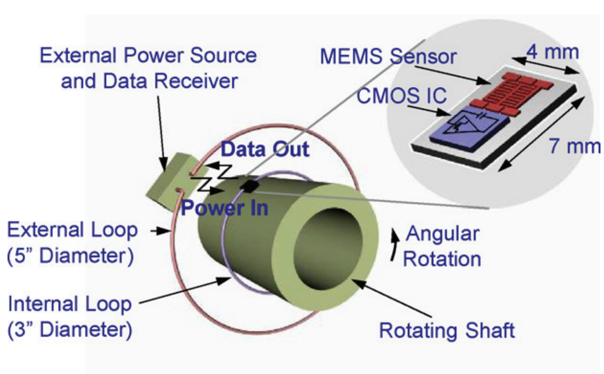


Fig. 6. Single-chip multi-function chemical gas detection systems [9] [Courtesy of Dr. A. Hierlemann of Physical Electronics Laboratory, Switzerland].

2.2. Sensor network and MEMS network

When the unit function MEMS systems established user trust and confidence in practical fields, it is time to develop large scale MEMS network system. There are cases that need many different functional systems working together, such as monitoring/control systems used in biomedical research on the behavior responses of living subjects to various stimulations. There also are situations that need many similar functional systems working



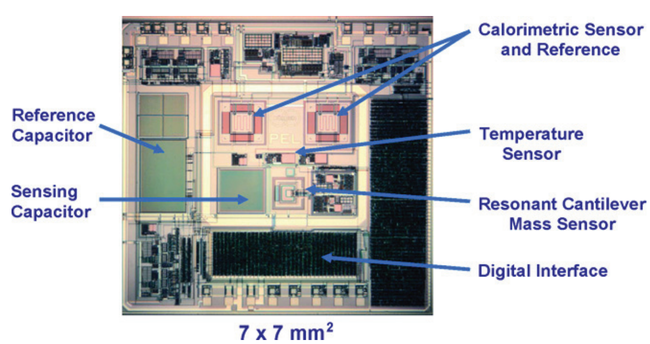


Fig. 7. Layout of single-chip multi-function chemical gas detection systems [9] [Courtesy of Dr. A. Hierlemann of Physical Electronics Laboratory, Switzer-

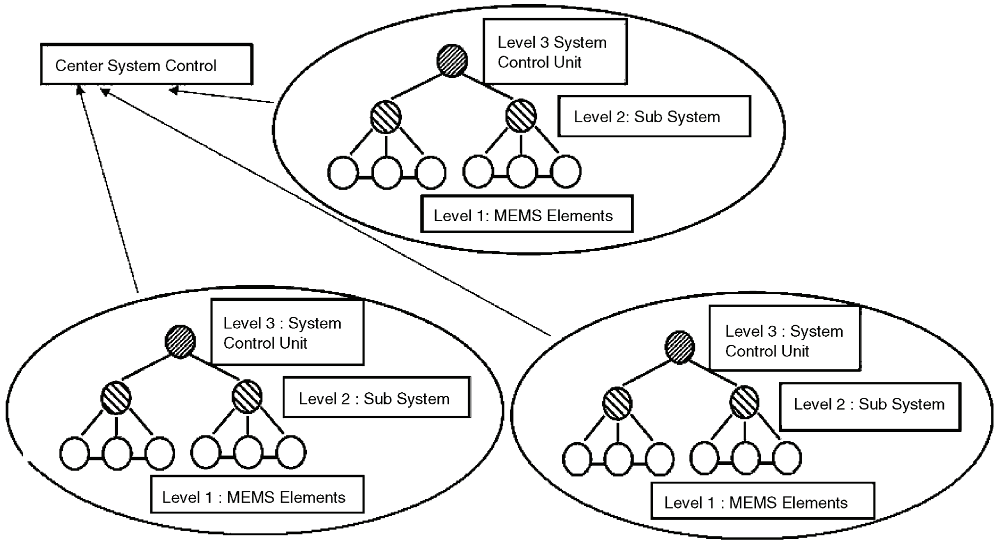


Fig. 8. A Schematic diagram of MEMS network organization [10].

together to perform a task, such as in the environmental research that needs similar systems to cover a large area under study. How to design these unit function MEMS systems so that hundreds or even thousands of similar and dissimilar systems can operate together as a functional network presents many challenges. For example, how to supply power to the thousands of unit systems in the network, how to program them so that they can communicate efficiently to each other and to the command center, etc. These will require research in theory/principle, design, technology, and operation software. Fig. 8 is a schematic diagram of a possible organization of the MEMS Network, which incorporated many unit function sensor-and-actuator-systems to build up a large system for designated purpose [10].

2.3. New MEMS materials and technology

Besides silicon and semiconductors, many other materials can be used for MEMS. Such as: alloys, mixture of ceramics, polymers, high temperature materials (SiC, Al_2O_3), giant magneto-resistive, and newly developed crystalline and non-crystalline materials, as well as nano-materials. Research to use these new materials for MEMS and packaging would be valuable. Fig. 9 is an example of the polymeric material field effect transistor [11].

2.4. New frontiers of MEMS research and application

Besides the traditional MEMS, many new frontiers of applications were opened up in recent years. Many more will be developed. The examples are.

2.4.1. Biological research and medical instruments

From DNA, protein, cell, organs, system biology studies, to biochips, micro-tools, and instrument, there are vast fields of research for MEMS in biomedical area. In medical field, from monitoring and therapeutic tools and diagnostic/therapeutic and implant instruments, MEMS should play a significant role in this attractive field of science and technology.

2.4.2. RF and optical communication

Cell phones, Internet, video display, etc.

In rf systems, rf switches, filters, modulators, and oscillators, as well as wireless consumer products are needed. In optical systems, switches, modulators, attenuators, display units, IFR communication, internet devices and control systems, as well as manufacturing industry and home monitoring, control, and automated devices and systems would be of interest.

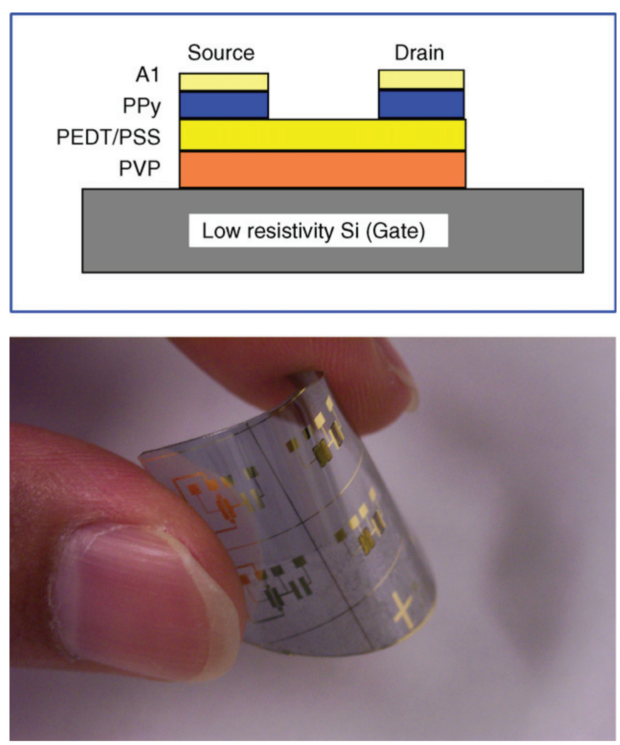


Fig. 9. A Polymeric material field effect transistor [11] [Curtsey of Dr. T. Cui

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